

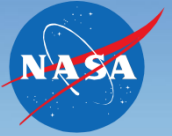
CORE NOISE – INCREASING IMPORTANCE

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Summary

This presentation is a technical summary of and outlook for NASA-internal and NASA-sponsored external research on core (combustor and turbine) noise funded by the Fundamental Aeronautics Program Subsonic Fixed Wing (SFW) Project. Sections of the presentation cover: the SFW system-level noise metrics for the 2015, 2020, and 2025 timeframes; turbofan design trends and their aeroacoustic implications; the emerging importance of core noise and its relevance to the SFW Reduced-Perceived-Noise Technical Challenge; and the current research activities in the core-noise area, with additional details given about the development of a high-fidelity combustor-noise prediction capability as well as activities supporting the development of improved reduced-order, physics-based models for combustor-noise prediction. The need for benchmark data for validation of high-fidelity and modeling work and the value of a potential future diagnostic facility for testing of core-noise-reduction concepts are indicated.

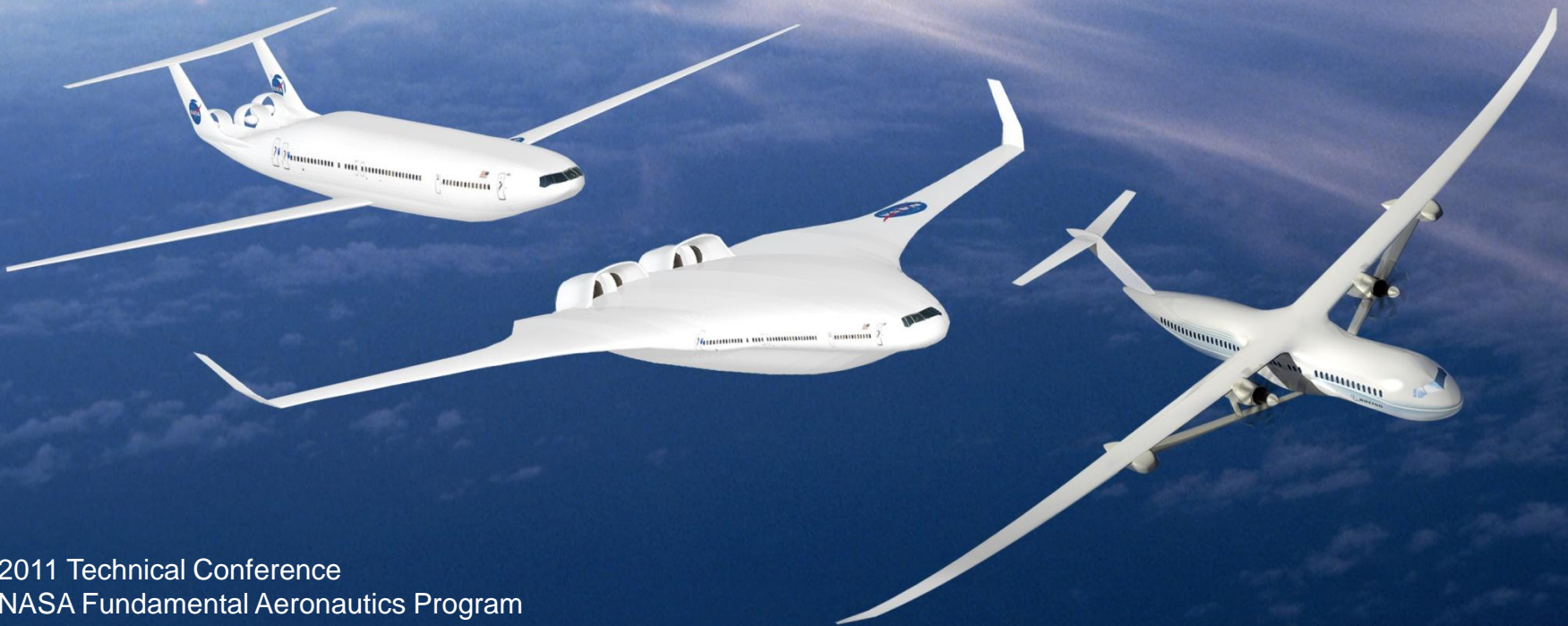
The NASA Fundamental Aeronautics Program has the principal objective of overcoming today's national challenges in air transportation. The SFW Reduced-Perceived-Noise Technical Challenge aims to develop concepts and technologies to dramatically reduce the perceived aircraft noise outside of airport boundaries. This reduction of aircraft noise is critical to enabling the anticipated large increase in future air traffic. Noise generated in the jet engine core, by sources such as the compressor, combustor, and turbine, can be a significant contribution to the overall noise signature at low-power conditions, typical of approach flight. At high engine power during takeoff, jet and fan noise have traditionally dominated over core noise. However, current design trends and expected technological advances in engine-cycle design as well as noise-reduction methods are likely to reduce non-core noise even at engine-power points higher than approach. In addition, future low-emission combustor designs could increase the combustion-noise component. The trend towards high-power-density cores also means that the noise generated in the low-pressure turbine will likely increase. Consequently, the combined result from these emerging changes will be to elevate the overall importance of turbomachinery core noise, which will need to be addressed in order to meet future noise goals.



Core Noise – Increasing Importance

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2011 Technical Conference
NASA Fundamental Aeronautics Program
Subsonic Fixed Wing Project
Cleveland, OH, March 15 - 17, 2011

Increasing Importance of Core-Noise

.... outline



❑ Introduction

- NASA Subsonic Transport System Level Metrics

❑ Turbofan design trends

- aero-acoustic implications
- emerging importance of core (combustor & turbine) noise
- current tools based on 1970-80s technology

❑ NASA FAP SFW core-noise activities

- internal and sponsored-external research efforts

❑ Summary

- needs and potential future direction

Develop aircraft noise-prediction capability and noise-reduction technologies

NASA Subsonic Transport System Level Metrics

... technology for dramatically improving noise, emissions, & performance



- Principal objective of the NASA FAP is to overcome today's national challenges in air transportation
- Reduction of aircraft noise is critical for enabling the anticipated large increase in future air traffic

CORNERS OF THE TRADE SPACE	N+1 (2015)*** Technology Benefits Relative to a Single Aisle Reference Configuration	N+2 (2020)*** Technology Benefits Relative to a Large Twin Aisle Reference Configuration	N+3 (2025)*** Technology Benefits
Noise (cum below Stage 4)	- 32 dB	- 42 dB	- 71 dB
LTO NO _x Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance Aircraft Fuel Burn	-33%**	-50%**	better than -70%
Performance Field Length	-33%	-50%	exploit metroplex* concepts

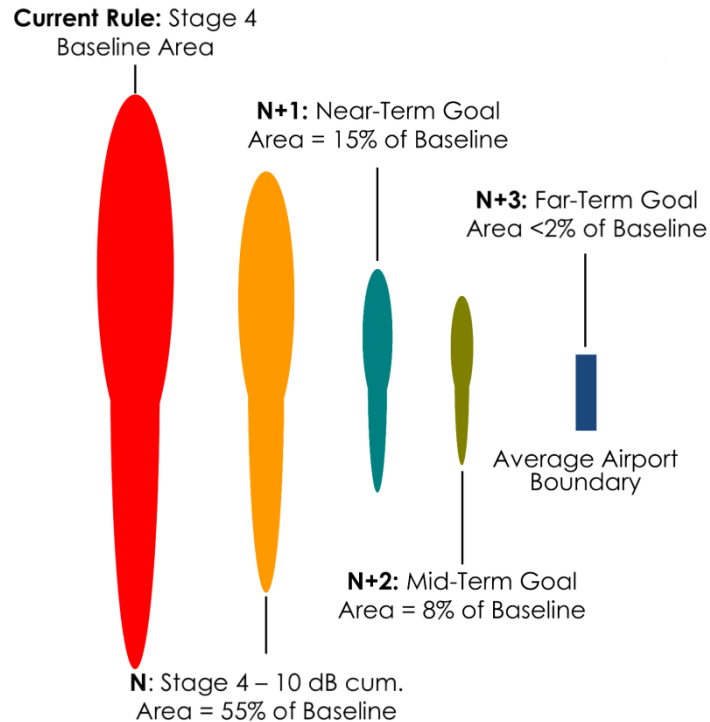
*** Technology Readiness Level for key technologies = 4-6

** Additional gains may be possible through operational improvements

* Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

SFW Reduce-Perceived-Noise Technical Challenge

... enable concepts & technologies to dramatically reduce perceived noise



Relative ground contour areas for notional Stage 4, current, and near-, mid-, and far-term goals

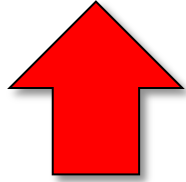
- ❑ NASA's N+3 noise goal is very aggressive
- ❑ Perceived noise limited to inside airport boundary
- ❑ How do these goals interact with design trends for emissions and performance
 - engine cycle
 - airframe configurations
- ❑ Limiting factors/issues?

Turbofan Design Trends

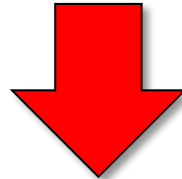
... overall cycle changes that will increase the relative importance of core noise



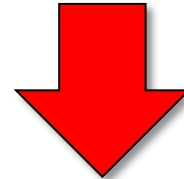
BPR



FPR



N1

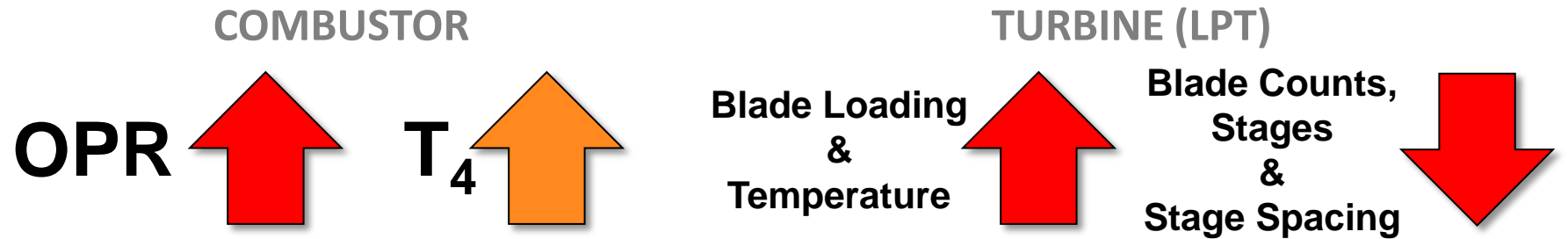


- ❑ Overall development towards increased by-pass ratio, BPR
 - ultra-high by-pass ratios: 10 – 20
 - jet noise reduced
- ❑ Decreased fan pressure ratio, FPR, and shaft speed, N1
 - decreased fan-tip speed
 - fan noise reduced
- ❑ Advances in fan-noise-reduction technology expected
 - acoustic treatment/liners and shielding

Non-core noise components will be further reduced at all power levels

Turbofan Design Trends

.... high-power-density, low-emission cores will increase core noise



- ❑ Increased overall pressure ratio, OPR – high OPR: 45 – 50
- ❑ Increased combustor exit temperature, T₄ (only some N+3)
- ❑ Lean-combustor technologies
- ❑ Increased blade loading and temperature
- ❑ Reduction in blade counts, number of stages and stage spacing

The trend towards advanced low-emission, high-power-density cores will increase core noise levels at all power settings

High-Power-Density, Low-Emission Cores

... potential acoustic implications & why core noise is important



- ❑ Core noise traditionally a concern only at approach, but ...
- ❑ Combustor noise increased due to
 - direct noise increases with $(OPR)^2$
 - low-emission designs could increase indirect noise
 - turbine design trends could lower transmission losses
 - implications from near-combustion-instability operation
- ❑ Low-Pressure-Turbine noise increased due to
 - stronger and more complex sources due to increased blade loading and decreased stage spacing
 - less attenuation due to decreased stage solidities
 - acoustic treatment more difficult due to increased temperatures

Emerging ultra-high-bypass-ratio engines with advanced high-power-density core components will make core noise a more significant component of the total engine noise signature at all power settings, which will need to be addressed to meet NASA noise goals

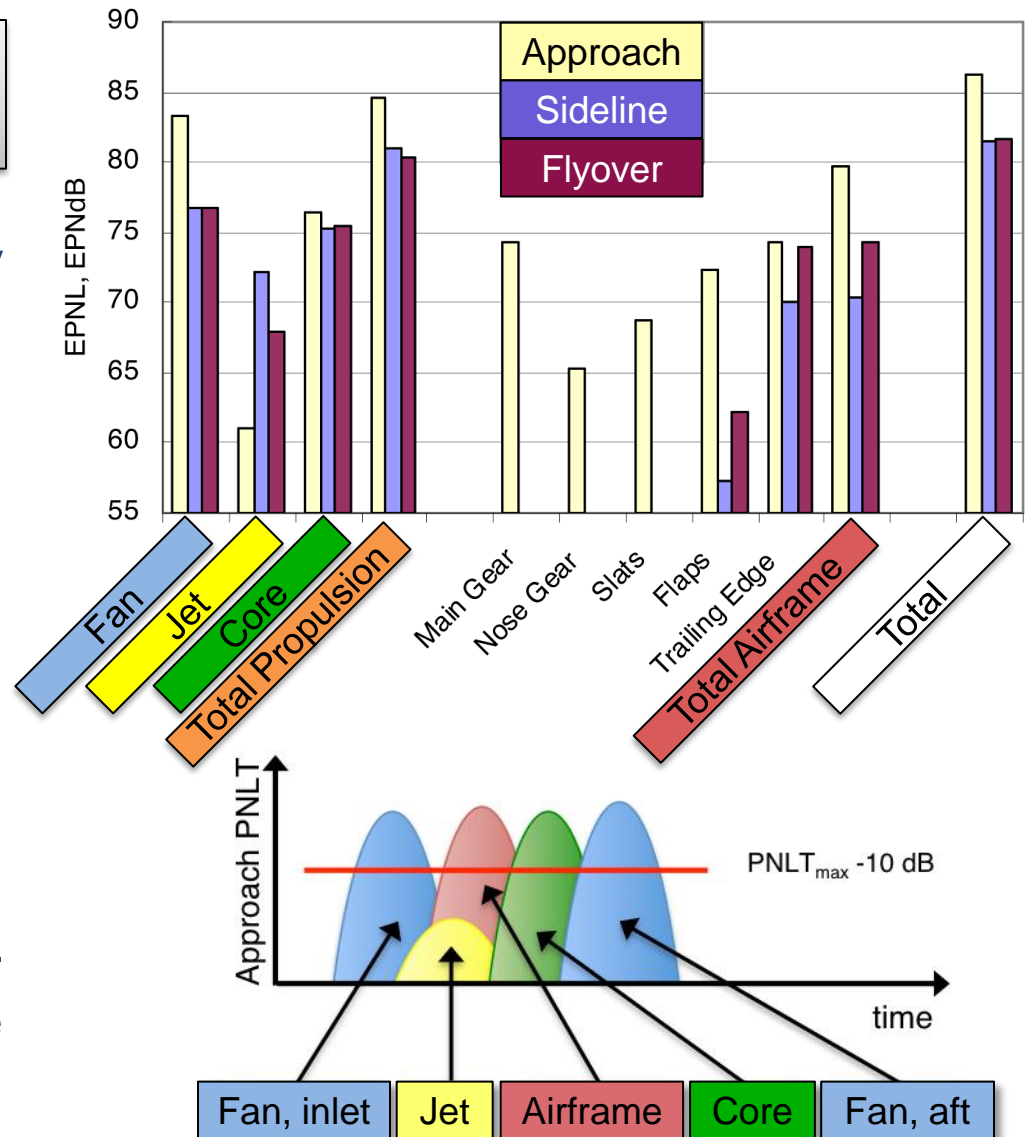
Predicted N+1 Airplane Certification Levels

... Jeffrey J Berton, Edmane Envia & Casey Burley – AIAA 2009-3144



$Thrust = 23,000\text{ lb}$; $BPR = 16$;
 $FPR = 1.3$; $OPR = 32$

- ❑ The N+1 predictions by Berton, Envia & Burley show that core noise is significant for takeoff and cutback conditions
- ❑ At approach:
 - fan-noise dominates EPNL due to tone penalties and duration
 - total-airframe then core-noise OASPL peaks are the largest

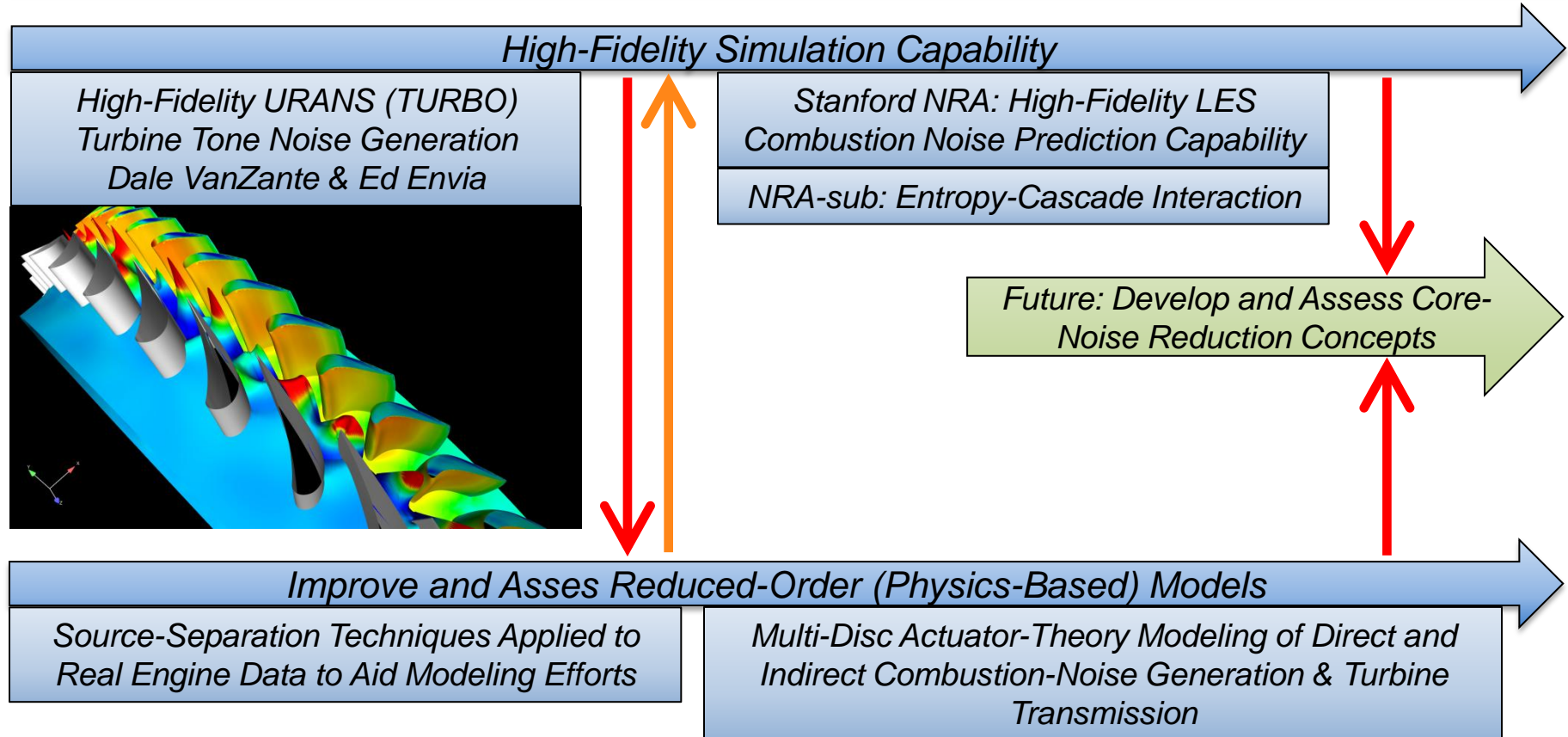


NASA FAP Core-Noise Activities

... previous and ongoing work

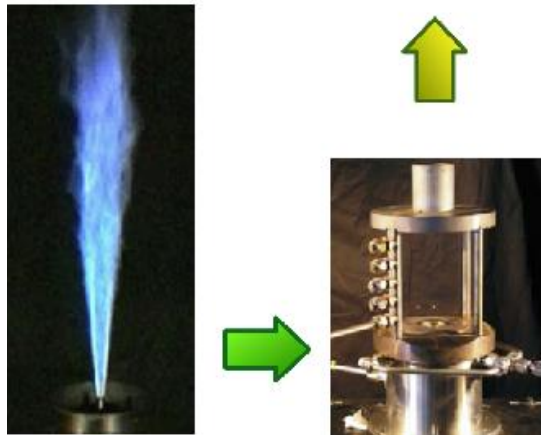
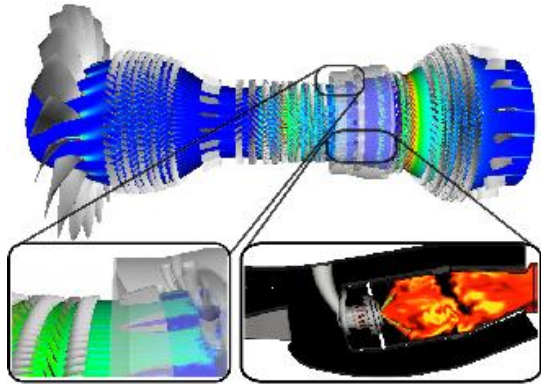


NASA Internal and NASA-Sponsored External Research Efforts Aimed at the Development of Aircraft Noise-Prediction Capability and Tools



High-Fidelity for Physics --- Modeling for Practical/Engineering Prediction

Stanford University – Professor Heinz Pitsch (5th & final year)
High-Fidelity LES Combustion Noise Prediction Capability



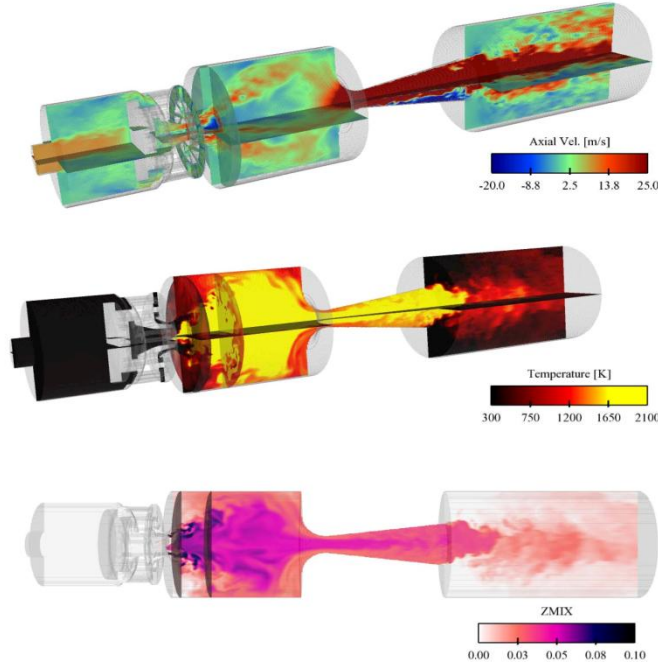
Reactive-Flow Model (CCLES)

- Advance Favre-filtered conservative variables $\{\rho, \rho\mathbf{u}, \rho\mathbf{z}, \rho c, \rho e\}^T$ using LES
- Chemistry tables provides mass fractions $Y_k(z, c)$
- Temperature from implicit relation
$$e = \sum Y_k h_k(T) - RT \sum Y_k / W_k + |\mathbf{u}|^2 / 2$$
- Pressure from $p = \rho RT \sum Y_k / W_k$

Initial Plan: address a sequence of problems –
free flame → combustor rig → realistic combustor
Reality: problem much harder than anticipated

Preliminary Simulation of Combustor-Rig Experiment

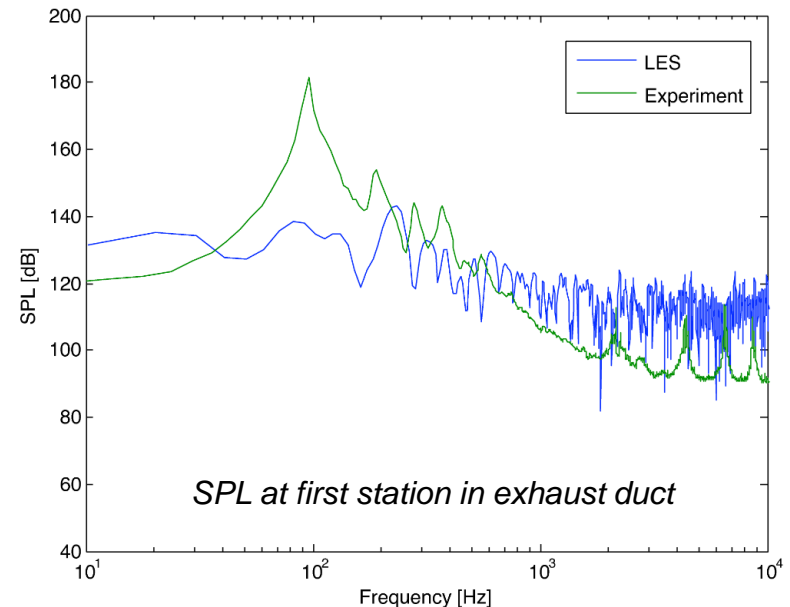
.... Stanford NRA work



Axial Velocity, Temperature, and Mixing Fraction

- ❑ High-freq. over prediction might be due to insufficient resolution in chemistry tabulation
- ❑ Higher-accuracy results not yet available

- ❑ Combustor-rig experiment at DLR, Germany
- ❑ Preliminary LES simulation at Stanford
- ❑ Results are comparable to existing self-excited URANS simulations by Bake et al

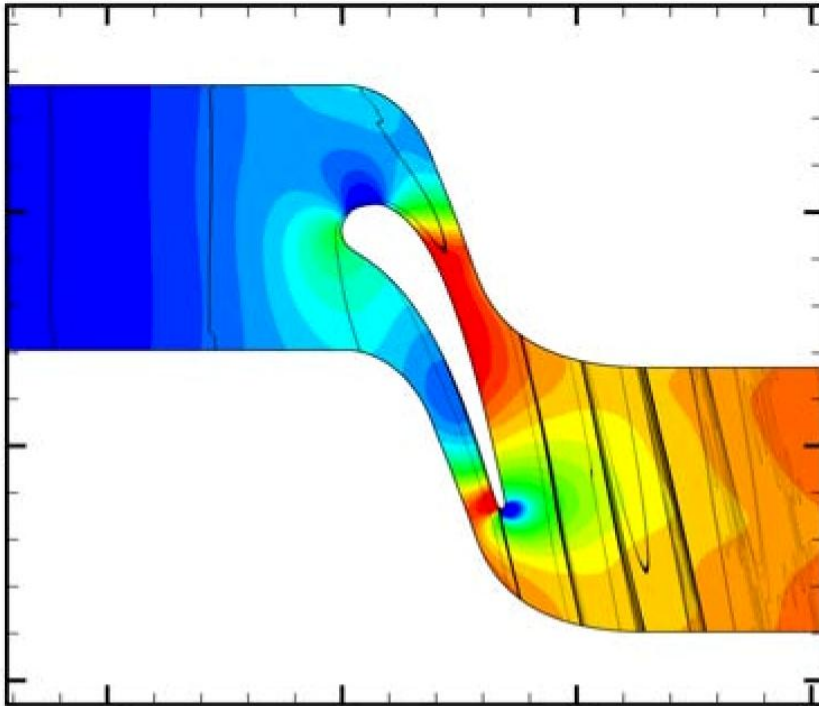


NASA FAP Core-Noise Activities

... ongoing NRA work (subcontract)



University of Illinois at Urbana-Champaign – Professor Daniel Bodony
High-Fidelity Simulation of Entropy-Cascade Interaction



1 kHz plane entropy wave interacting with cascade and producing sound waves – figure shows instantaneous unsteady density (lines) and unsteady pressure (contours)

- High-fidelity LES simulation of scattering of entropy perturbations into sound

Phys. Fluids **21** (096101), 2009

- Both localized and plane-wave entropy disturbances and stationary blade row

AIAA/CEAS Aeroacoustics Conference, 2011

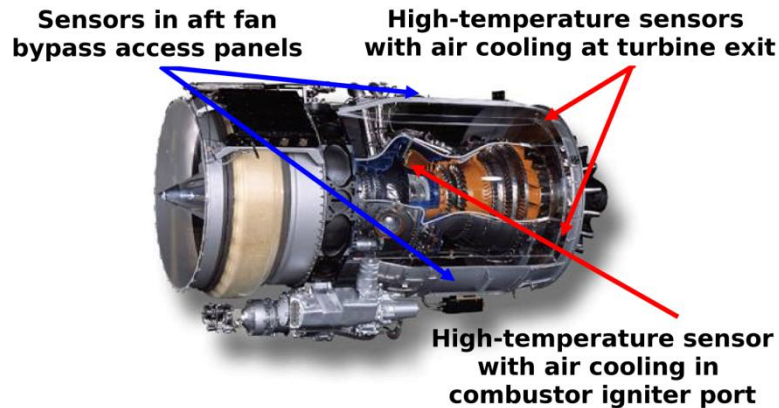
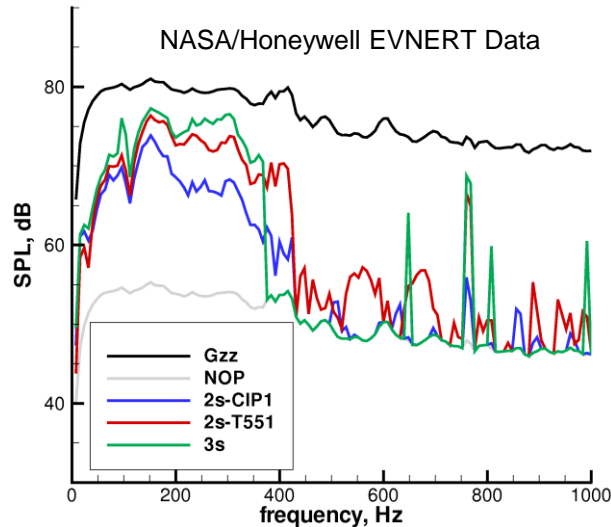
- Aim is to validate and extend actuator-disk theory
- Stator-rotor calculations have been initiated

NASA FAP Core-Noise Activities

... ongoing NASA in-house research efforts



Source-separation techniques applied to real-engine data to aid modeling



Honeywell TECH977 Turbofan

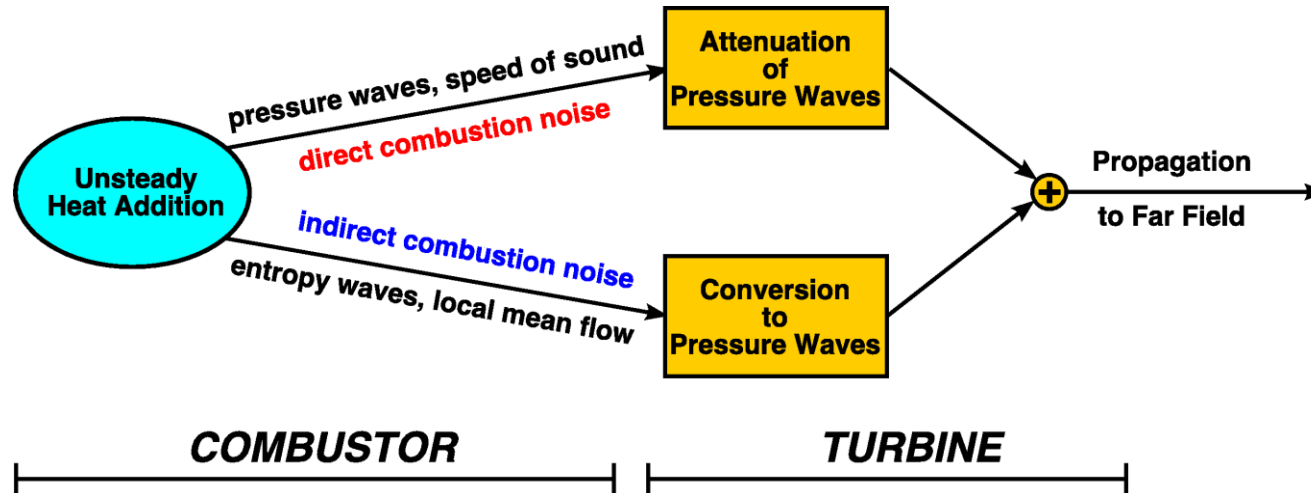
- ❑ Presence of jet noise makes measurement difficult
 - combustor noise masked by jet noise during static engine test
- ❑ Assessment and development of source separation methods
 - necessary aid in developing improved reduced-order models
 - applied to real engine data
 - aligned and unaligned coherence
 - J. H. Miles: AIAA 2006-0010
 - new additional discriminator for three-signal method
 - L. S. Hultgren & J. H. Miles: AIAA 2009-3220
 - indirect combustor noise

NASA FAP Core-Noise Activities

... ongoing NASA in-house research efforts



Dual paths of combustion noise (direct & indirect)



□ Direct and indirect noise

- same low frequency range
- relative importance uncertain
- source-separation analysis: indirect noise present in real-engine data

J. H. Miles: J. Propulsion Power **25** (1), 2009; J. Propulsion Power **26** (2&5), 2010

- multi-disc actuator-theory modeling of generation and turbine transmission of direct and indirect noise

Summary

.... NASA FAP SFW Core-Noise Program



❑ Background

- existing prediction capability for core (combustor & turbine) noise is based on empiricism
- core noise needs to be addressed to meet noise goals

❑ Current FAP SFW Core-Noise Activities

- high-fidelity work to better understand the physics
- reduced-order models for improved prediction
- source-separation techniques in order to validate models
- lack of benchmark data for validation of both high-fidelity work and improved models

❑ Future directions and needs

- evaluate acoustic implications of emerging N+3 concepts
- high-fidelity and reduced-order-modeling work needs support by high-quality experimental data for real-engine conditions
- diagnostic capability for testing of core-noise reduction concepts

